SBGf422

Major Types of Deep-Water Reservoirs from the Eastern Brazilian Rift and Passive Margin Basins

Carlos H.L. Bruhn

Petrobras E&P, Rio de Janeiro, Brazil

Abstract

Turbidites and associated deep-water facies comprise the most important petroleum reservoirs in Brazil. They contain original *in place* volumes of 57.2 billion bbl of oil, and 27.5 trillion cubic feet of gas, and total reserves of 12.5 billion bbl of oil, and 8.3 trillion cubic feet of gas. Brazilian petroleum-bearing turbidites occur in (1) Carboniferous/Permian, glaciomarine pre-rift (interior cratonic) successions, (2) Neocomian to Aptian, lacustrine rift successions, and (3) Upper Albian to Lower Miocene, marine passive margin successions. Most of the petroleum accumulations are distributed along the eastern Brazilian margin, which tectonic and sedimentary evolution is linked to the Neocomian breakup of Gondwana and the subsequent opening of the South Atlantic Ocean. Turbidites comprise 553 production zones from 171 oil and/or gas fields, mostly concentrated in the Campos, Recôncavo, Sergipe/Alagoas, and Espírito Santo basins. This paper presents an overview of the sedimentary facies, high-resolution stratigraphy, sandbody geometry, and reservoir heterogeneities of the major types of Brazilian deep-water reservoirs, which include (1) gravel/sand-rich, turbidite channel complexes, (2) trough-confined, gravel/sand-rich turbidite lobes, (3) unconfined, sand-rich turbidite lobes, (4) sand/mud-rich turbidite lobes, (5) gravel/sand-rich turbidite and debrite aprons, (6) deposits of sand-rich, lacustrine density underflows, (7) deposits of sand/mud-rich debris flows, and (8) deposits of sandy bottom currents.

Turbidites and associated deep-water facies comprise the most important petroleum reservoirs in Brazil (Figs. 1 and 2). They contain original *in place* volumes of 57.2 billion bbl of oil, and 27.5 trillion cubic feet of gas, and total reserves of 12.5 billion bbl of oil, and 8.3 trillion cubic feet of gas. Brazilian petroleum-bearing turbidites occur in (1) Carboniferous/Permian, glaciomarine pre-rift (interior cratonic) successions, (2) Neocomian to Aptian, lacustrine rift successions, and (3) Upper Albian to Lower Miocene, marine passive margin successions. Most of the petroleum accumulations are distributed along the eastern Brazilian margin (Fig. 3), which tectonic and sedimentary evolution is linked to the Neocomian breakup of Gondwana and the subsequent opening of the South Atlantic Ocean (Fig. 4). Turbidites comprise 553 production zones from 171 oil and/or gas fields, mostly concentrated in the Campos, Recôncavo, Sergipe/Alagoas, and Espírito Santo basins (Fig. 3).

This paper is intended to provide an overview of the sedimentary facies, high-resolution stratigraphy, sandbody geometry and internal heterogeneities of the major types of deep-water reservoirs from the eastern Brazilian margin. Brazilian deep-water reservoirs have been studied in detail by geologists, geophysicists, and reservoir engineers for almost 60 years. These studies have shown that the Brazilian deep-water reservoirs comprise different types and can be very complex and heterogeneous. The major types of Brazilian deep-water reservoirs are named below, and their stratigraphic position is indicated in Fig. 4. They can be discriminated mainly on the basis of grain size, net-to-gross ratio, sandbody geometry, depositional processes, and depositional setting:

(1) **Gravel/sand-rich, turbidite channel complexes (CC):** 10-50 m-thick, 200-2,000 m-wide (mostly 200-800 m-wide), and 0.5->10 km-long channel-fills, which can be clustered into 20-100 m-thick, 1-6 km-wide, and 1->10 km-long channel complexes. **CC** reservoirs have a complex, multi-storied geometry resulting from the amalgamation of many channel-fills and partial preservation of overbank/levee and/or background deposits between channel-fills. **CC** reservoirs typically fill fault-bounded troughs and canyons in deep lacustrine rifts, canyons incised into the shelf, and troughs incised into the slope in areas with slope oversteepening due to intense faulting and upward movement of underlying evaporites.

(2) **Trough-confined, gravel/sand-rich turbidite lobes (GSLc):** 10-140 m-thick, 1-12 km-wide, and 3->20 km-long tabular/lobate reservoirs confined to intra-slope troughs defined by subsidence along listric faults soling out on underlying evaporites and erosion by high-density turbidity currents.

(3) **Unconfined, sand-rich turbidite lobes (SLuc):** 5-60 m-thick, 1-8 km-wide, and 2-12 km-long lobes filling intra-slope, wide depressions with low bottom gradients, which were developed by downslope gliding of underlying evaporites. Some lobes can be heavily dissected **(SLucd)** by low- to high-sinuosity, 5-15 m-deep, 200-600 m-wide channels.

(4) **Sand/mud-rich turbidite lobes (SML):** 2-20 m-thick, 1-20 km-wide, and 2->20 km-long lobes, which are composed of turbidite sandstones and frequently interbedded background mudstones and debris flow deposits. They occur in similar settings as those for **SLuc** reservoirs, or originated from sliding/slumping of sediments previously accumulated on steep-fronted, flexural margin deltas that prograded over deep lacustrine, rift basins.

(5) **Gravel/sand-rich aprons (AP):** up to 2 km-thick, 5-20 km-wide, and 5-200 km-long wedges deposited by high-density turbidity currents and debris flows along border fault margins of lacustrine rifts.

(6) **Deposits of sand-rich, lacustrine density underflows (DU):** up to 50 m-thick, 600-1,200 m-wide, and 1.5-4.5 km-long sandbodies, which are confined to narrow (< 5 km), fault-bounded troughs subparallel to the border fault margins of deep lacustrine rifts.

(7) **Deposits of sand/mud-rich debris flows (DF):** Mounded to channelized, up to 400 m-thick, 200-4,000 m-wide, and 0.8-5 km-long muddy sandstone bodies, which were deposited by debris flows derived from the slumping of deltaic systems prograding into deep lacustrine rifts.

(8) **Deposits of sandy bottom currents (BC):** Elongated mounds (up to 35 m-thick, up to 20 km-wide, and over 25 km-long) transversely-oriented to the slope. **BC** mounds are composed of interbedded mudstones and thin-bedded, rippled sandstones, which overlie some of the most proximal **SLuc** reservoirs; i.e. those accumulated in slope depressions, near the lower reaches of canyons that feeded the sand-rich turbidite systems. **BC** reservoirs seem to have been deposited by tide-related currents that flow up and down some submarine canyons.

CC reservoirs have the largest stratigraphic distribution, occurring in the continental rift, marine transgressive, and marine regressive megasequences. **GSLc** reservoirs are restricted to the marine transgressive megasequence. **SLuc** and **BC** reservoirs are exclusive of the marine regressive megasequence. **SML** reservoirs occur both in the continental rift and marine transgressive megasequences, but they comprise a much larger number of oil and/or gas fields in deep lacustrine, rift basins. **AP** reservoirs are typical of the continental rift megasequence, but can be found in the transitional megasequence of a few basins. **DU** and **DF** reservoirs are described only from deep lacustrine, rift basins.

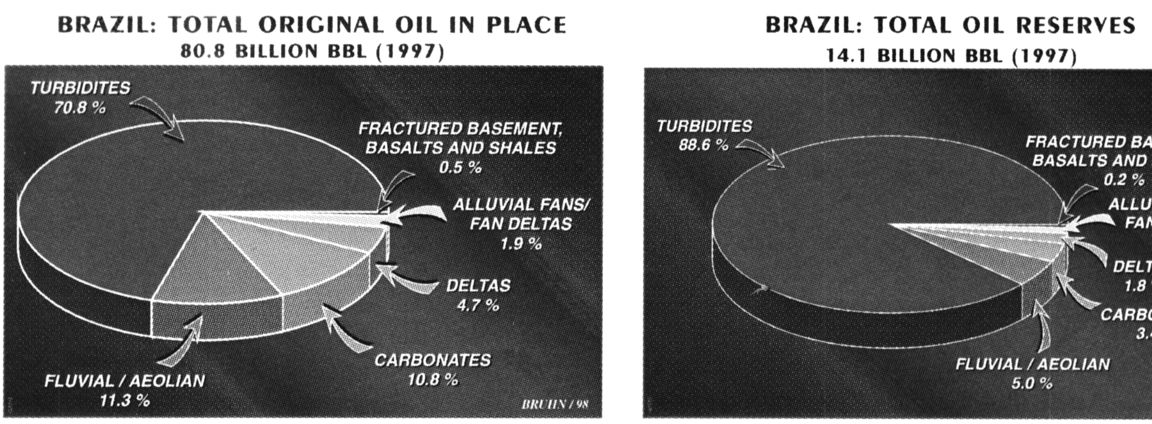

Fig. 1 - Brazilian original (*in place*) oil volumes, and oil reserves distributed by different depositional systems.

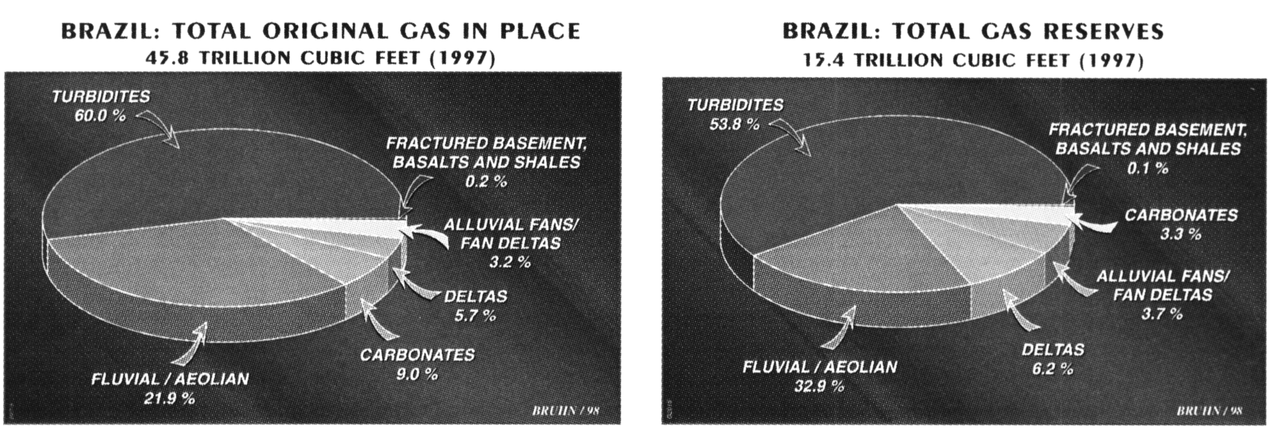

Fig. 2 - Brazilian original (*in place*) gas volumes, and gas reserves distributed by different depositional systems.

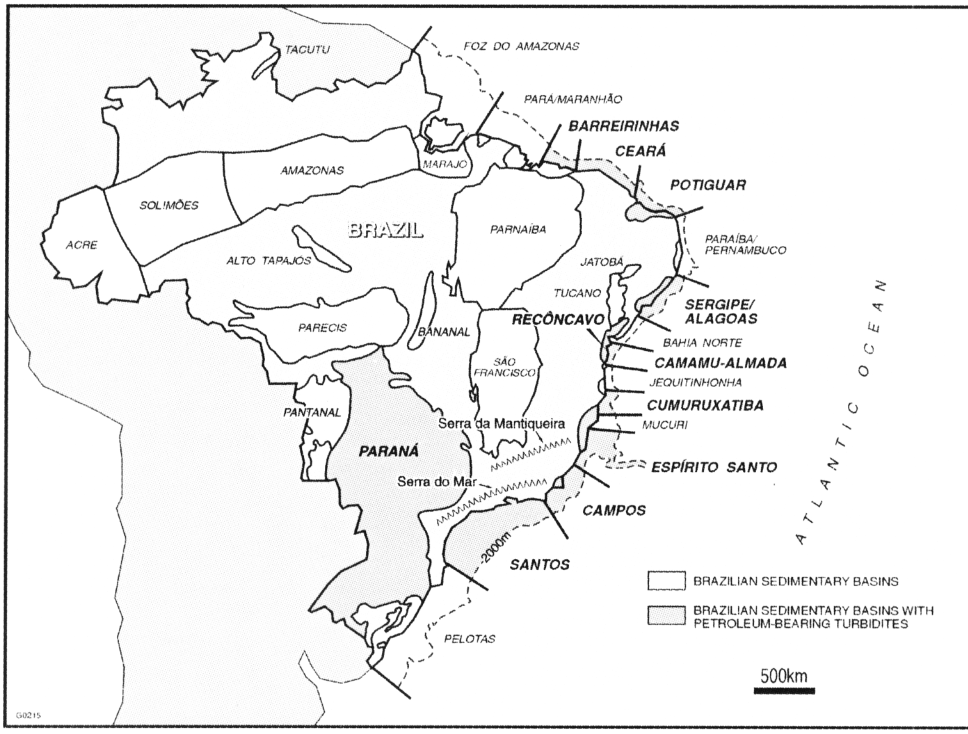

Fig. 3 – Location map for the most important Brazilian sedimentary basins.

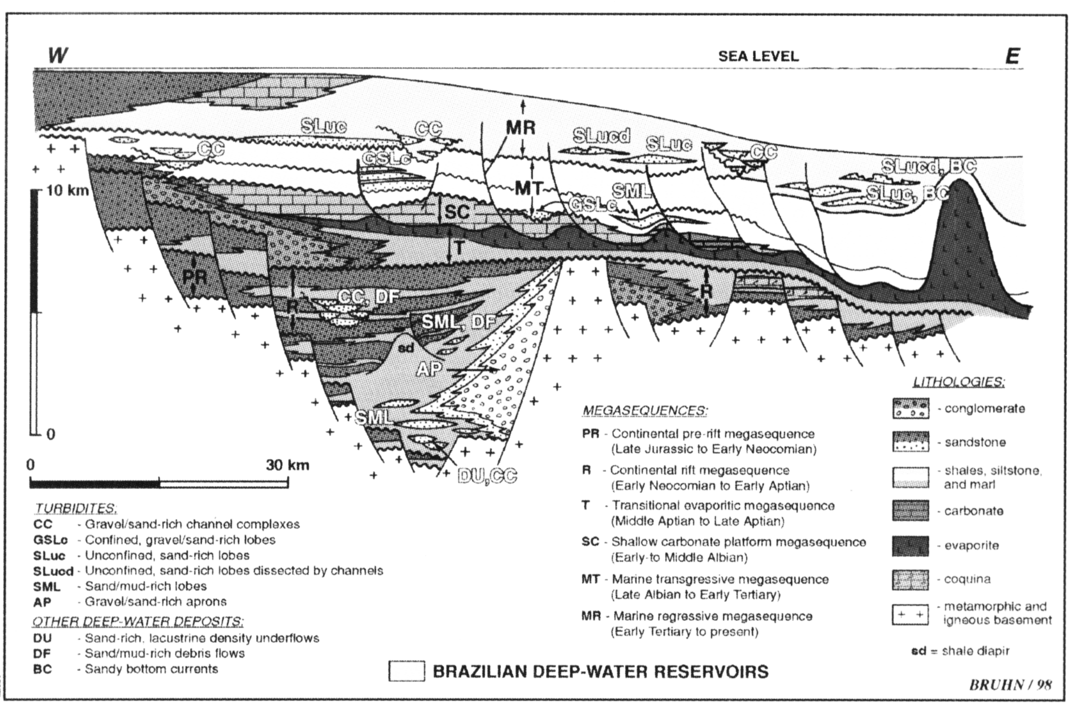

Fig. 4 – Generalized geological section for the eastern Brazilian marginal basins. Deep-water reservoirs are highlighted in yellow.

The lateral transition from **CC** to **GSLc** reservoirs (the two most important reservoirs from the marine transgressive megasequence) is still poorly understood. Although time-equivalent **CC** and **GSLc** reservoirs have been found in different basins (e.g. Maastrichtian **CC** reservoirs in the Espírito Santo and Almada basins, and Maastrichtian **GSLc** reservoirs in the Campos Basin), the lateral transition between these two turbidite types has not been documented so far in the marine transgressive megasequence of the eastern Brazilian margin. Possible lateral transitions from **CC** to **SLuc** reservoirs (the most important reservoirs from the marine regressive megasequence) are also still poorly understood. The **SLuc** reservoirs from the Oligocene/Miocene section of deep water Campos Basin were mostly fed by low-sinuosity, mud-filled channels; only a few **SLuc** lobes are succeeded upstream by **CC** reservoirs. Conversely, very little is known about the downstream, more distal portion of the **CC** reservoirs of the same age. However, **CC** and **SLuc** reservoirs can be time equivalent along basin strike. In this context, **CC** reservoirs accumulated preferentially in areas with slope oversteepening due to intense faulting and upward movement of underlying Aptian evaporites, and **SLuc** reservoirs typically fill intra-slope, wide depressions with low (<1°) bottom gradients, which were developed by the withdrawal of underlying Aptian evaporites. **BC** reservoirs typically overlie the most proximal **SLuc** reservoirs, i.e. those accumulated in upper to middle-slope depressions near the lower reaches of the canyons that feeded the sand-rich turbidite systems. **SML** and **DF** reservoirs are commonly associated, making part of the filling-section of highly-subsiding, fault-bounded troughs. Both types probably originated from the sliding and slumping of sediments accumulated on steep-fronted, flexural margin deltas, which prograded over deep lacustrine, rift basins. **AP** reservoirs are line-sourced systems, mostly accumulated along highly-subsiding, border fault margins of rift basins; they are laterally associated and interbedded with deep lacustrine mudstones, **CC** reservoirs, and axially-oriented **DU** reservoirs.

Figures 5 and 6 show the distribution of oil and gas original volumes and reserves in Brazilian deep-water reservoirs, according to the major types of deep-water reservoirs described above. **SLuc** reservoirs are, by far, the most important reservoirs in Brazil, because they comprise thick, widespread, homogeneous (up to 125 m thick without interbedded mudstones), and highly porous and permeable sandbodies. **GSLc** reservoirs also comprise thick, homogeneous, and highly porous and permeable sandbodies, but have a smaller areal distribution (and volume). **CC** reservoirs tend to be more heterogeneous, and have a more complex geometry than **GSLc** reservoirs; however, **CC** reservoirs can be as important as **GSLc** reservoirs because they occur both in onshore and offshore basins, and comprise a much larger number of oil and/or gas fields. All the other types combined (**SML**, **AP**, **DU**, and **DF**) contain only 1.9% of the oil reserves, and 8.4% of the gas reserves; this can be explained by their smaller size, more complex geometry, and lower porosities and permeabilities. **SML** reservoirs are more important as gas reservoirs because they comprise a larger number of gas accumulations in the older and deeper sections from the continental rift megasequence. **AP** and **DF** are typical tight gas reservoirs. **BC** reservoirs contain only minor and still poorly evaluated oil and gas accumulations in present day deep water areas.

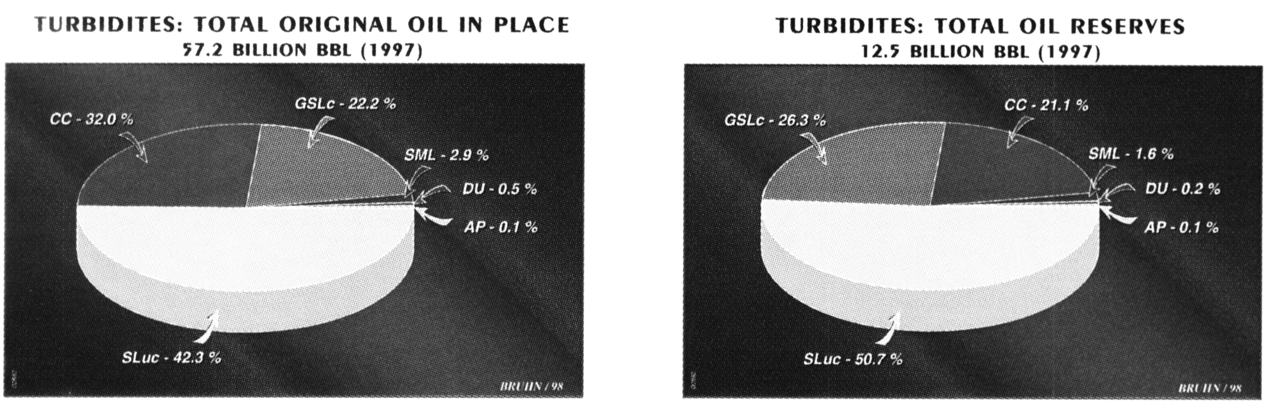

Fig. 5 – Distribution of original oil volumes and oil reserves in Brazilian deep-water reservoirs. **CC**=Gravel/sand-rich, turbidite channel complexes, **GSLc**=Trough-confined, gravel/sand-rich turbidite lobes, **SLuc**=Unconfined, sand-rich turbidite lobes, **SML**=Sand/mud-rich turbidite lobes, **AP**=Gravel/sand-rich turbidite and debrite aprons, **DU**=Deposits of sand-rich, lacustrine density underflows. **DF** (Deposits of sand/mud-rich debris flows) and **BC** (Deposits of sandy bottom currents) contain only minor oil accumulations.

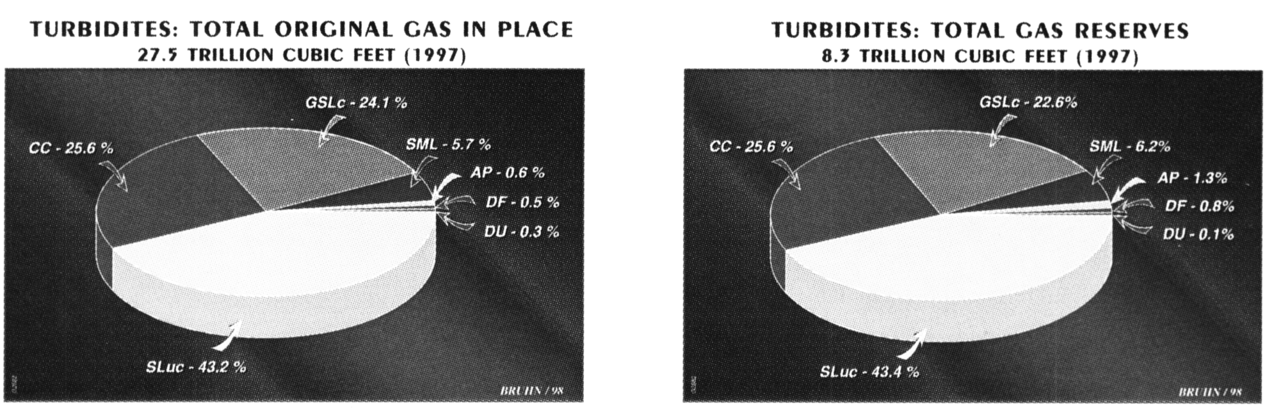

Fig. 6 – Distribution of original gas volumes and gas reserves in Brazilian deep-water reservoirs. **CC**=Gravel/sand-rich, turbidite channel complexes, **GSLc**=Trough-confined, gravel/sand-rich turbidite lobes, **SLuc**=Unconfined, sand-rich turbidite lobes, **SML**=Sand/mud-rich turbidite lobes, **AP**=Gravel/sand-rich turbidite and debrite aprons, **DU**=Deposits of sand-rich, lacustrine density underflows, **DF**=Deposits of sand/mud-rich debris flows. **BC** (Deposits of sandy bottom currents) contain only minor gas accumulations.